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(54) Abstract Title
Measuring coarse frequency offset of a multi-carrier signal

(57) Apparatus for measuring the coarse frequency offset of a multi-carrier or OFDM signal comprising a plurality of sub-carriers at a known nominal relative spacing, the signal including a symbol block including a substantially self-orthogonal sequence which repeats across the sub-carriers, said apparatus including means for processing said multi-carrier signal to obtain a signal having a generally regular data structure, and means for applying a comb filter function generally matched to said structure thereby to deduce the coarse frequency offset of said multi-carrier signal.

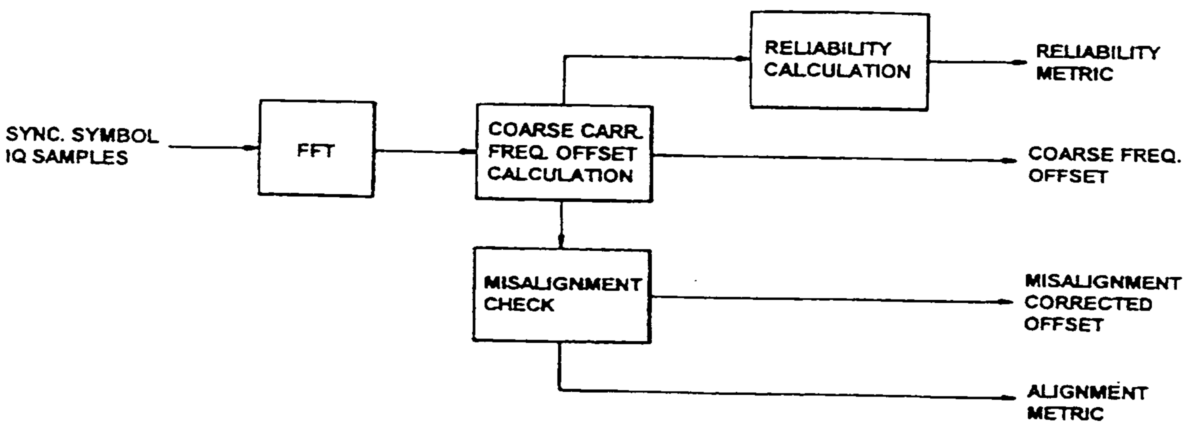


Fig. 4

GB 2 320 868 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

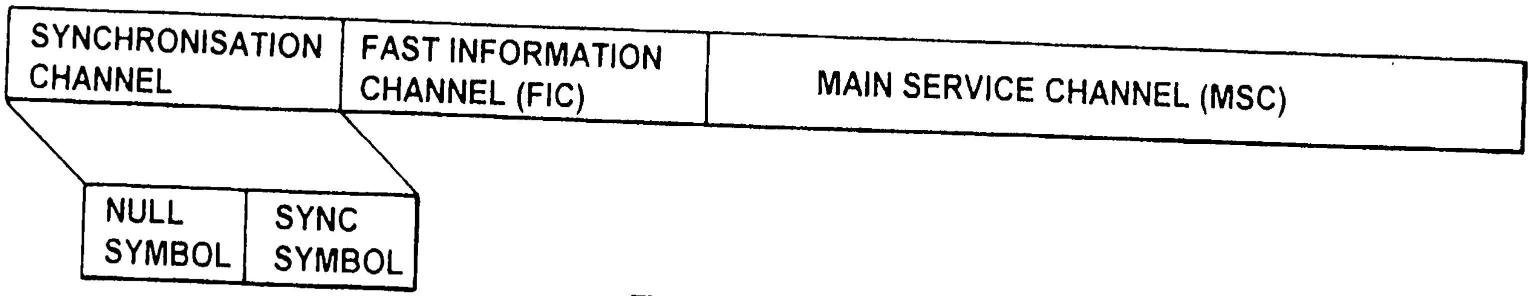

SYNCHRONISATION CHANNEL
FAST INFORMATION CHANNEL (FIC)
MAIN SERVICE CHANNEL (MSC)
NULL SYMBOL
SYNC SYMBOL

Fig. 1

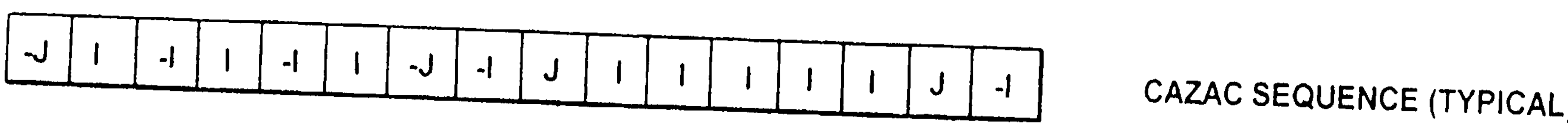

-J
I
-I
I
-I
I
-J
-I
J
I
I
I
I
I
J
-I
CAZAC SEQUENCE (TYPICAL)

Fig. 2

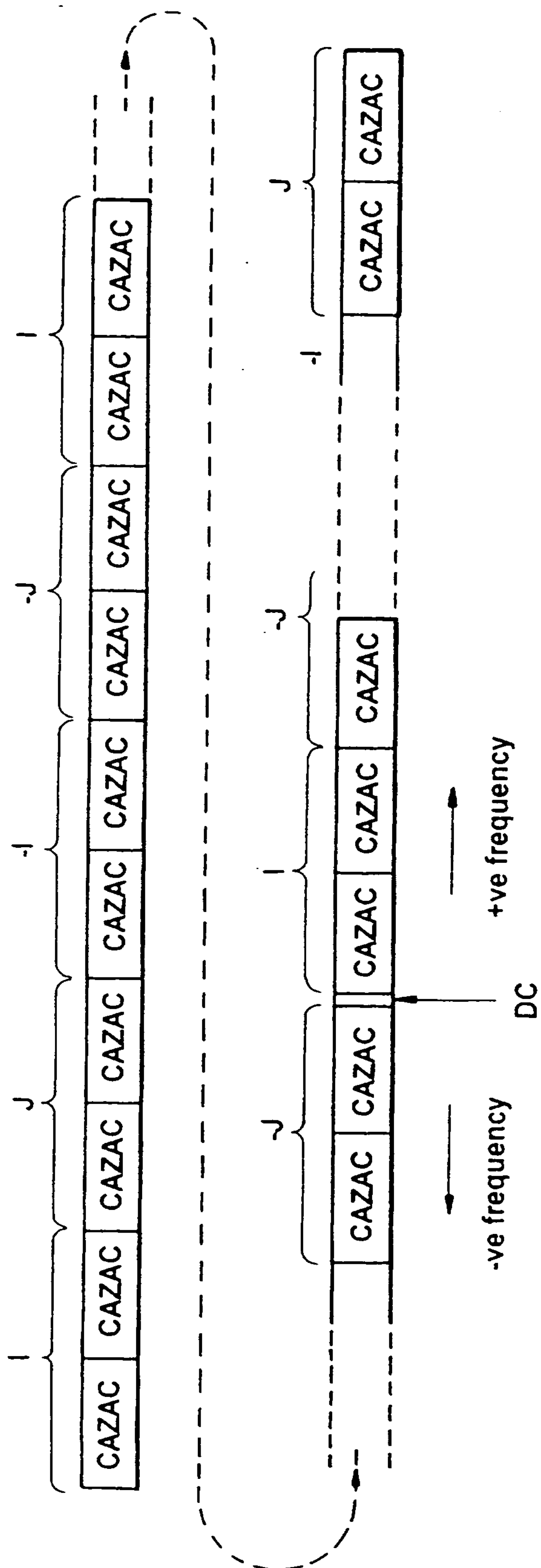


Fig. 3

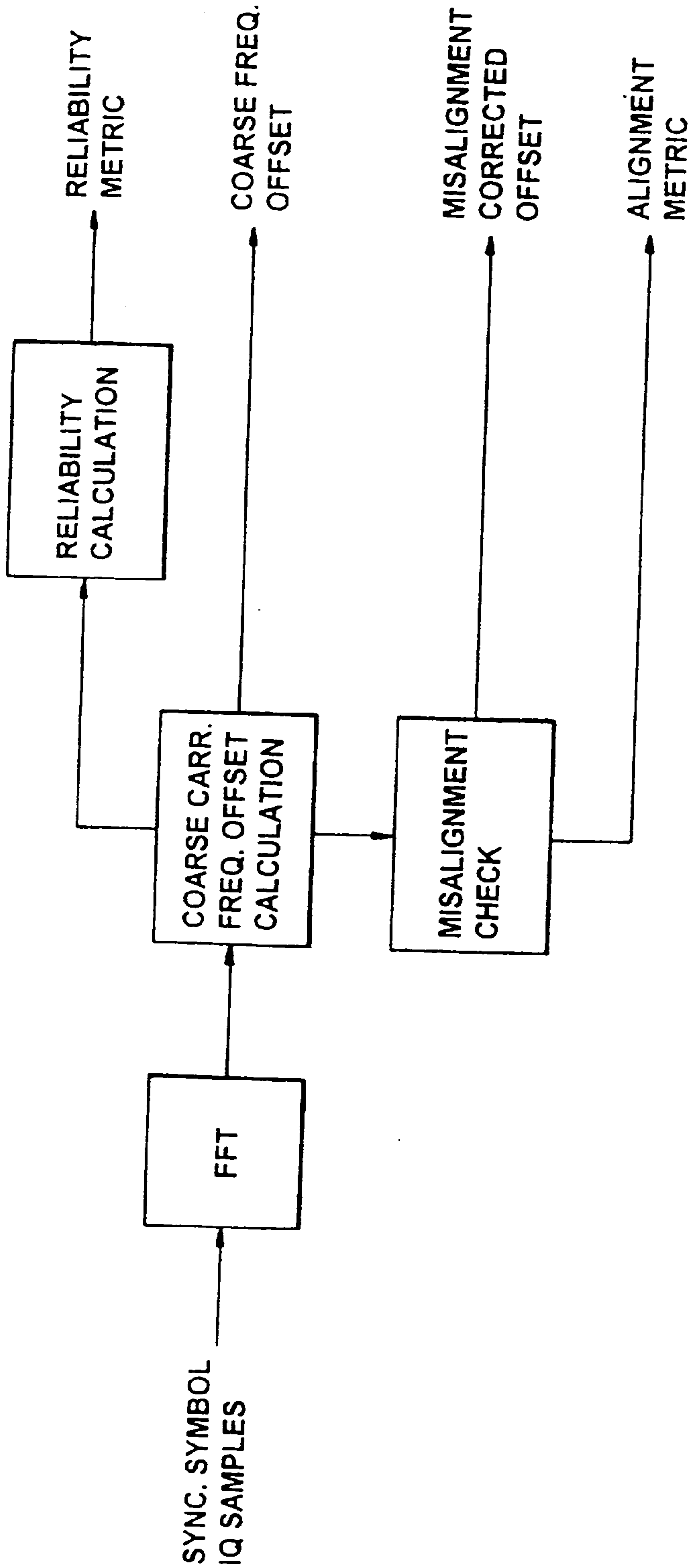
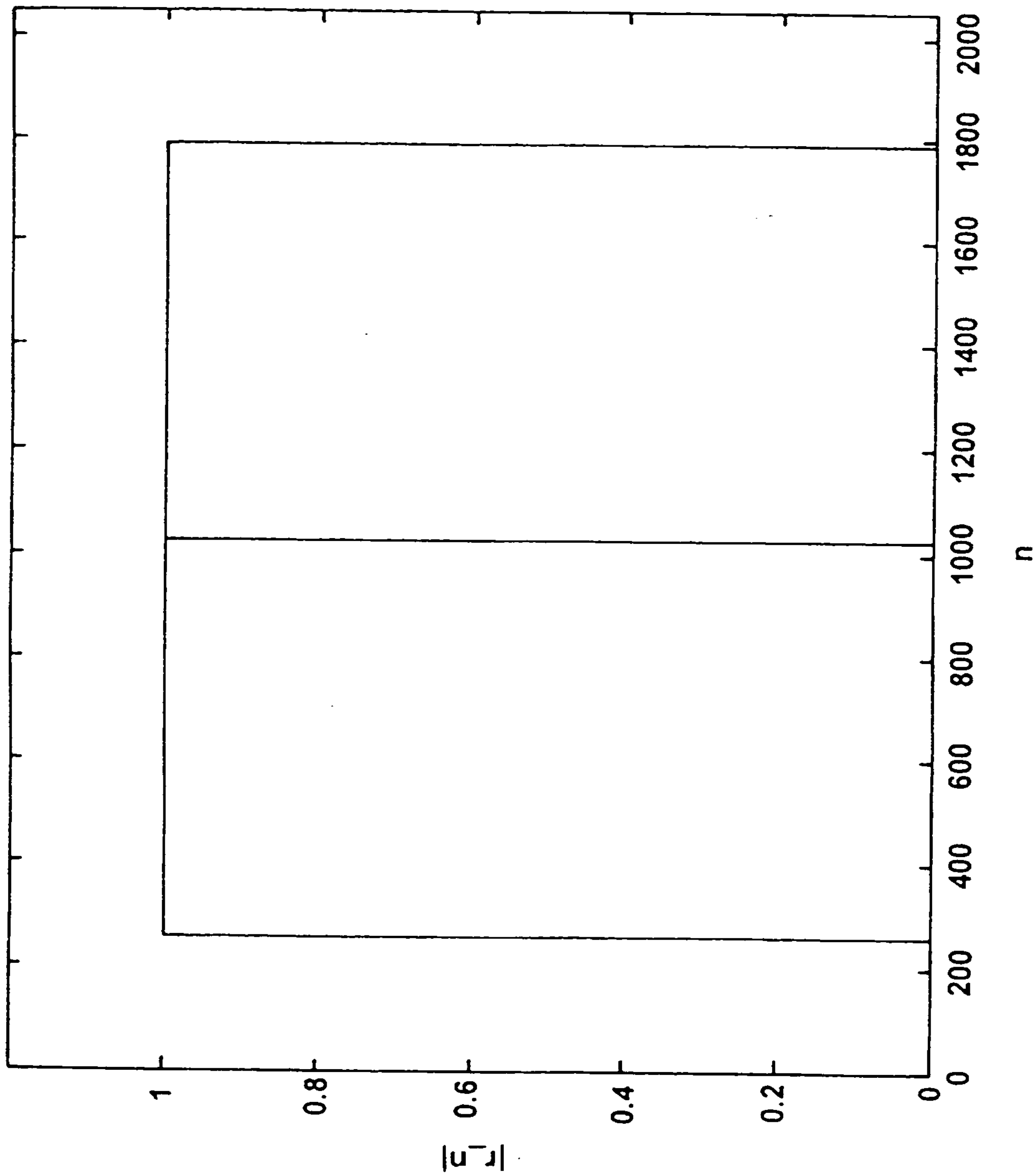
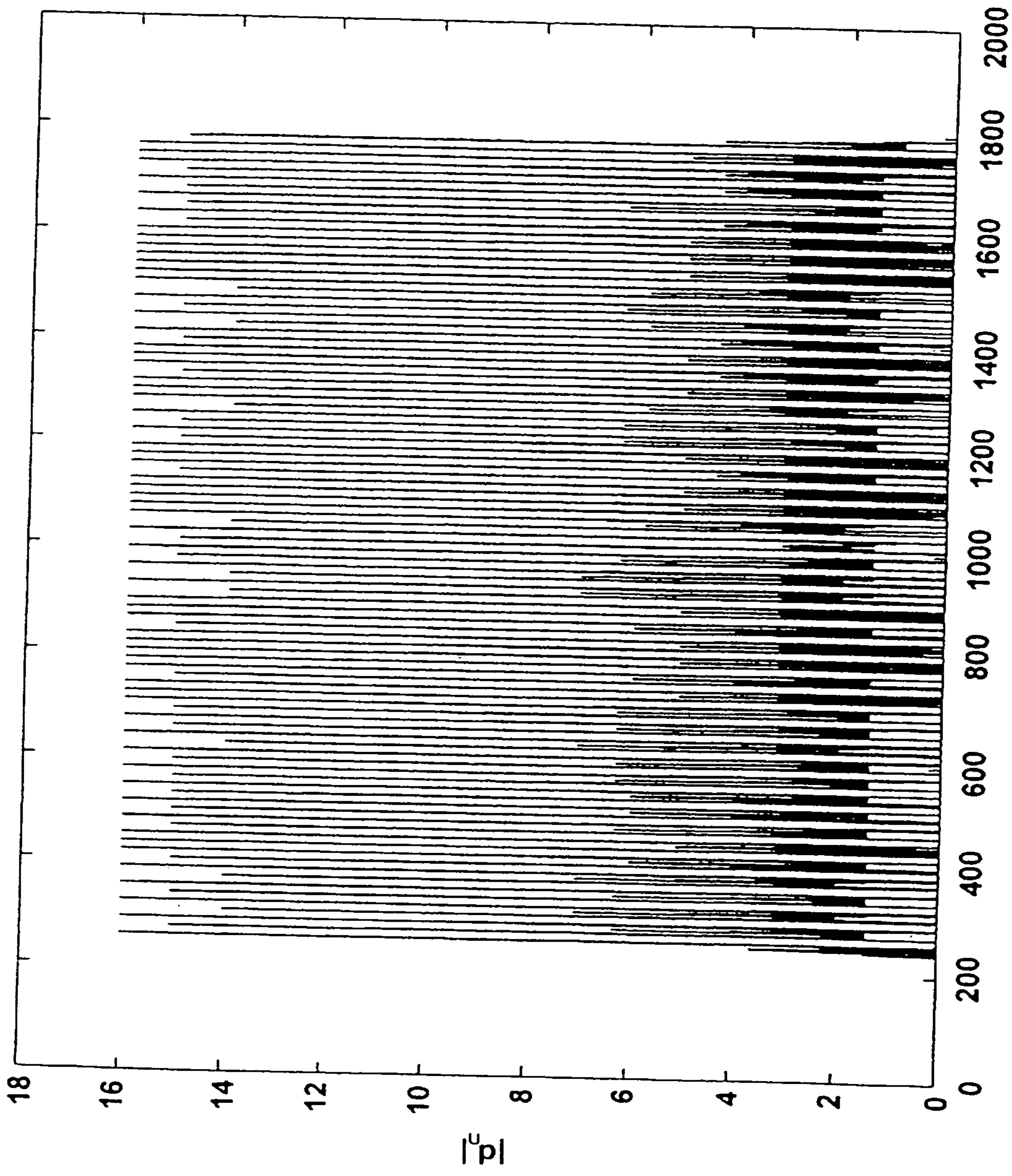

RELIABILITY METRIC
COARSE FREQ. OFFSET
MISALIGNMENT CORRECTED OFFSET
ALIGNMENT METRIC
RELIABILITY CALCULATION
COARSE CARR. FREQ. OFFSET CALCULATION
MISALIGNMENT CHECK
FFT
SYNC. SYMBOL IQ SAMPLES

Fig. 4



|r_n|
n
0
0.2
0.4
0.6
0.8
1
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Fig. 5



|d_n|
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2
4
6
8
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12
14
16
18
0
200
400
600
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1000
1200
1400
1600
1800
2000

Fig. 6

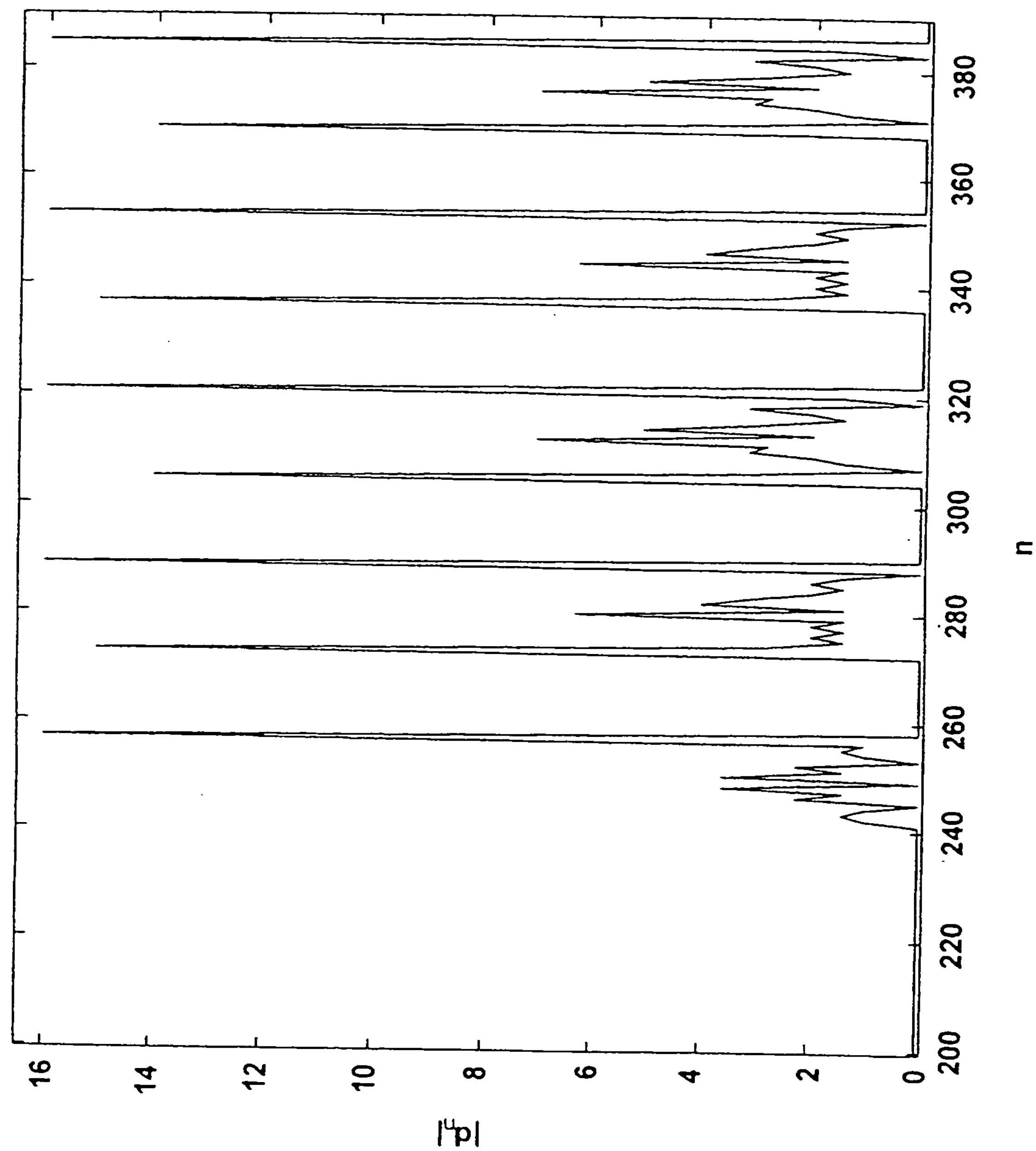
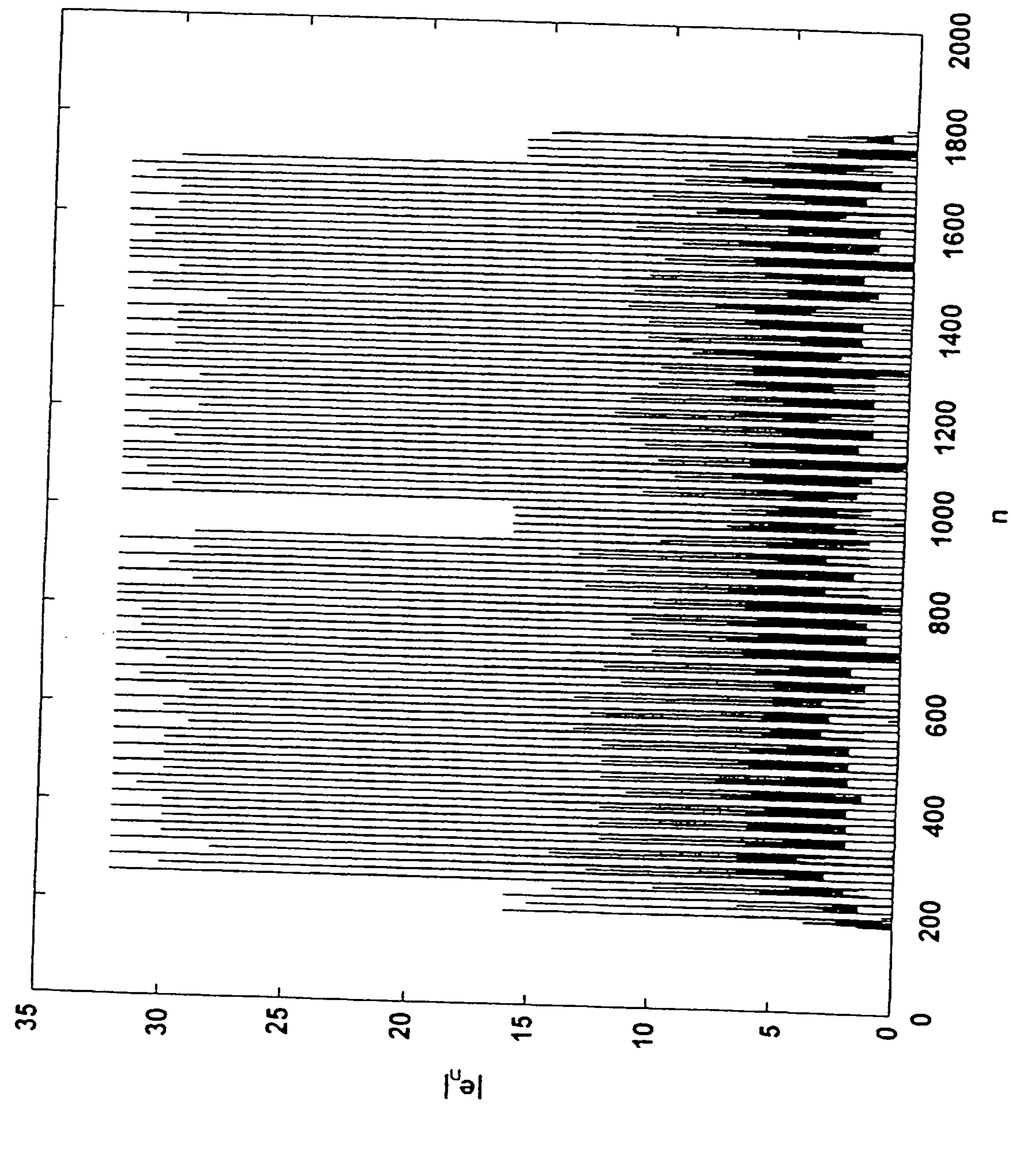


Fig. 7



35
30
25
20
15
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|e_n|
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600
800
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1200
1400
1600
1800
2000
n

Fig. 8

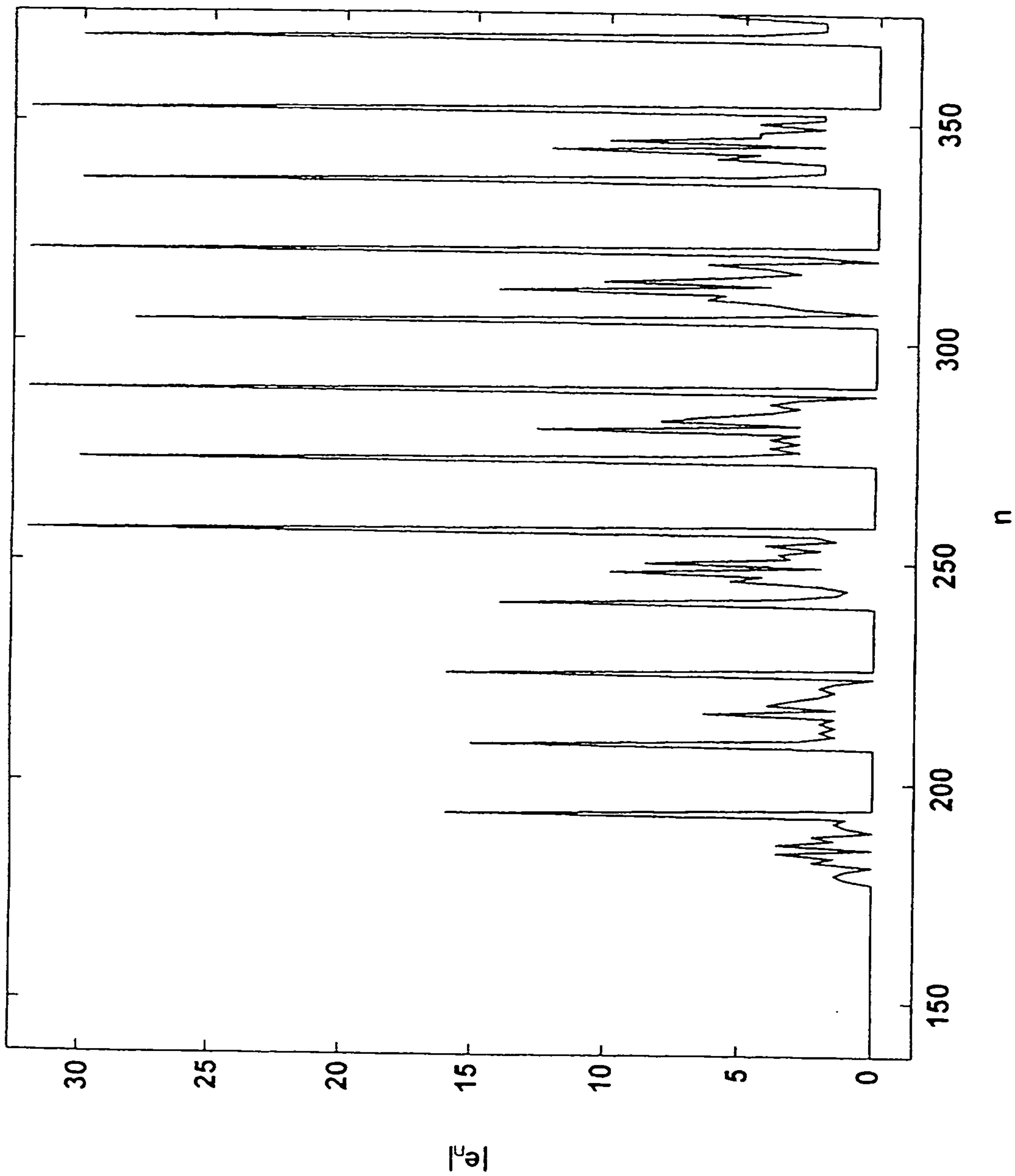
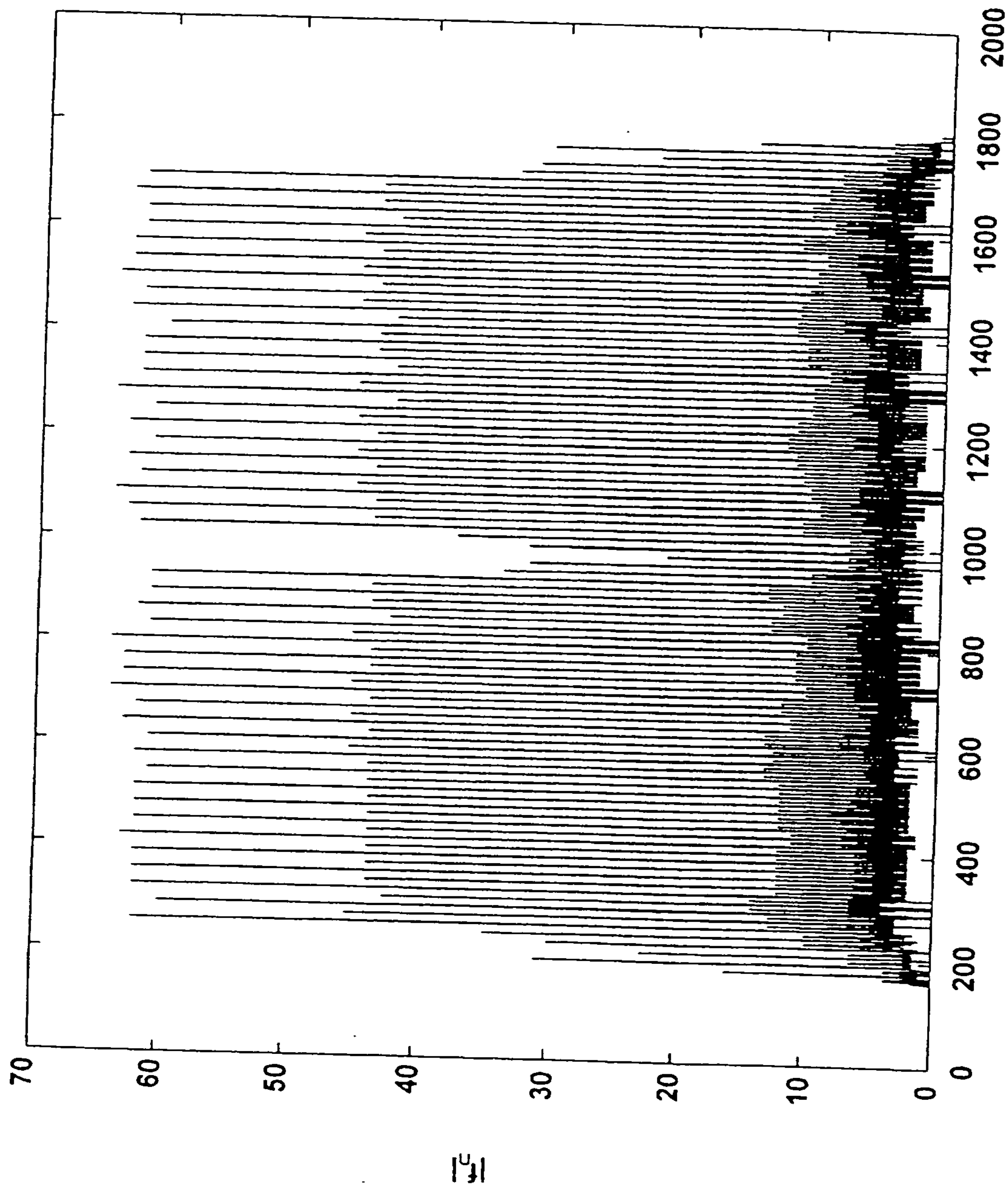


Fig. 9



70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
n
|f_n|

Fig. 10

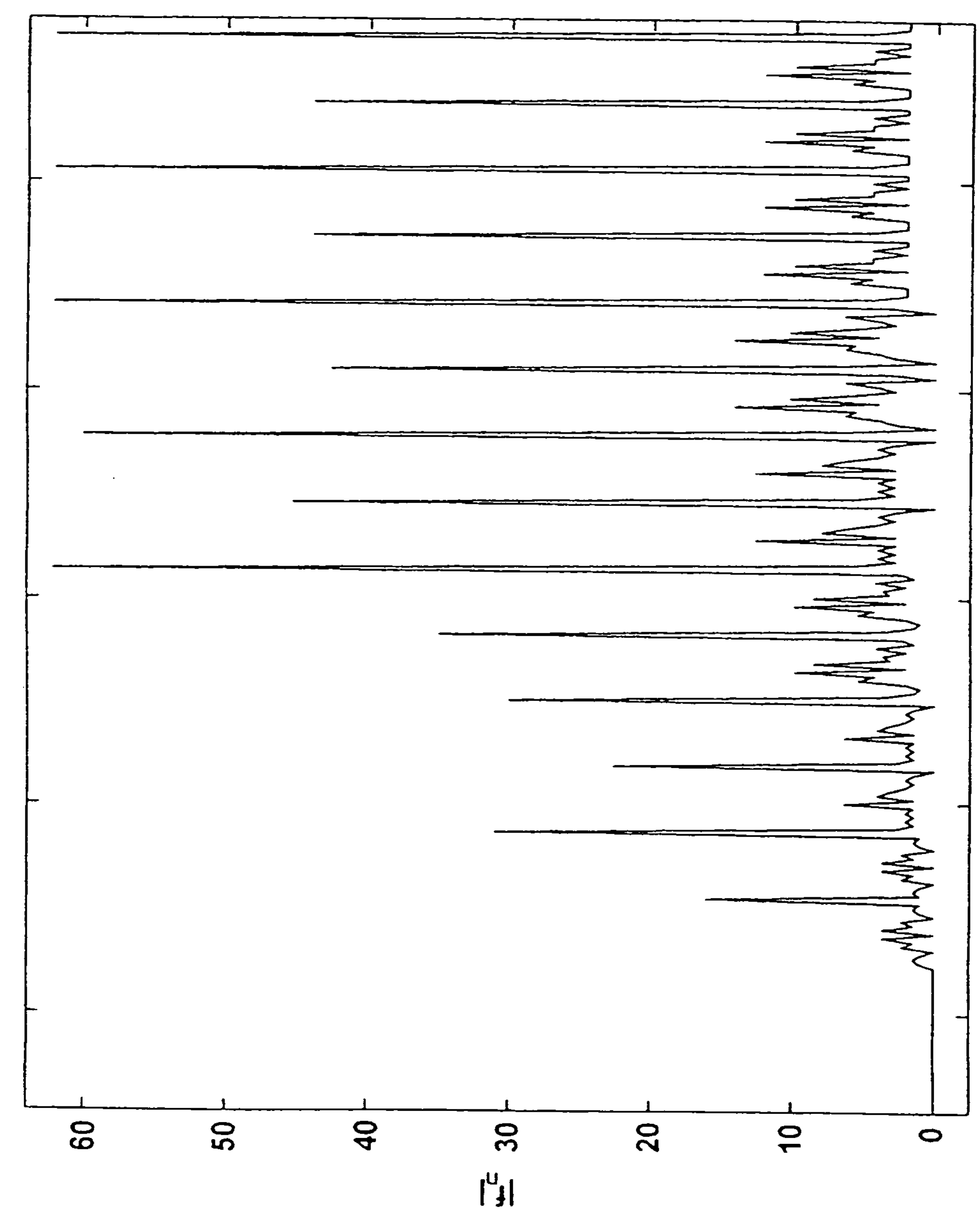
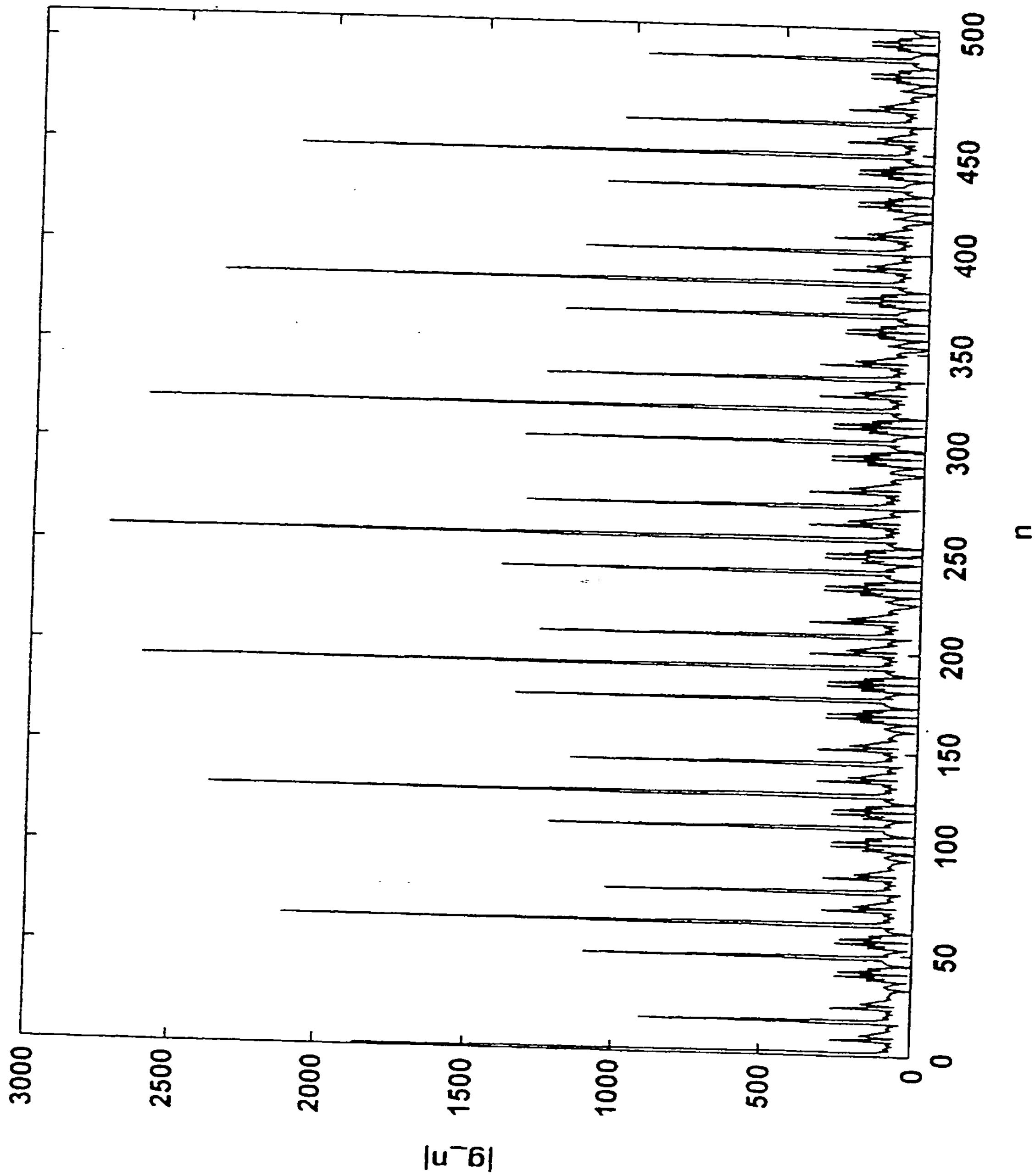


Fig. 11



|g_n|
n
0
500
1000
1500
2000
2500
3000
0
50
100
150
200
250
300
350
400
450
500

Fig. 12

APPARATUS AND METHODS FOR MEASURING COARSE FREQUENCY OFFSET OF A MULTI-CARRIER SIGNAL

This invention relates to apparatus and methods for determining the gross carrier frequency offset of an orthogonal frequency division multiplex (OFDM) or multi-carrier modulation signal. In particular, but not exclusively, the invention relates to such apparatus and methods for use in determining the gross carrier frequency of signals conforming to the Eureka 147 DAB (digital audio broadcast) transmission standard set out in European Telecommunications Standard ETS 300401, "Radio broadcast systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers". The invention is however equally applicable to many other multi-carrier modulation signals which incorporate synchronisation symbols which contain substantially self-orthogonal sequences.

The Eureka 147 DAB transmission standard (Modes I, II, III, and IV) is a digital transmission system which employs coded orthogonal frequency division multiplexing (COFDM). COFDM is a wide band modulation scheme designed to make efficient use of the spectrum whilst having increased resistance to fading and to the problems caused by multi-path reception. COFDM achieves this by encoding data onto a large number of closely spaced sub-carriers at a relatively low symbol rate and occupying a wide bandwidth. For example in Eureka 147 DAB mode I, there are 1536 sub-carriers spaced at 1 kHz intervals transmitting at a rate of

800 symbols per second. With suitable coding such as quadrature phase shift keying (QPSK), each symbol encodes two bits, giving an overall data rate of about 2.5 Megabits/sec.

In the Eureka 147 DAB standards, the data is transmitted as a frame made up of a null symbol, a synchronisation or "sync" symbol followed by a number of information or main service channel symbols. The null symbol is used by the receiver to obtain a timing signal. The sync symbol provides a number of functions. Operating with the received version of this symbol, together with the known transmitted signal provides the impulse response of the channel and from this a much more accurate timing can be obtained. The sync symbol also allows a frequency offset between the transmitter and receiver to be estimated.

It is important in COFDM schemes to ensure that the offset between the carrier frequencies of the transmitter and the receiver are accurately matched, typically to within 5% of the sub-channel spacing. Usually, the relative spacing of the sub-carriers at the transmitter and receiver will be set by the software and so it is the gross frequency offset which requires attention, especially during the signal acquisition stage. To aid receiver synchronisation in time and frequency, it is common for the sync symbol to be of known form with special properties (a constant amplitude zero autocorrelation (CAZAC) sequence), and transmitted at a regular, but infrequent rate.

The sync symbol provides coarse and fine frequency

information as well as acting as a phase reference symbol for subsequent DQPSK modulated symbols. The sync symbol used in Eureka 147 DAB is based on the repetitive use of a short length CAZAC sequence which is repeated in pairs (and successive pairs being rotated by multiples of $\pi/2$) in a regular manner to occupy all the sub-carriers in the sync symbol block.

European Patent Application No. 92113788.1 describes the use of the CAZAC sequence for both coarse and fine frequency offset measurement in COFDM transmissions. In this earlier Application, the coarse carrier offset measurement is based on the straightforward use of the properties of the CAZAC sequence, namely that the autocorrelation between two CAZAC sequences is zero for all cyclic shifts other than the zero shift. For a CAZAC sequence of length 16, as used in Eureka 147 DAB, the described technique allows coarse frequency offset measurements of approximately ± 8 sub-carriers (e.g. ±8 kHz in Mode I transmissions).

However the ability to determine coarse frequency offset of ± 8 kHz is extremely limiting. Several iterations would be required to scan a block of spectrum of reasonable width and this could be time consuming and computationally intensive. Indeed this limitation could result in placing an unnecessary limitation on the broadcast standards.

Accordingly there is a need for a coarse frequency offset frequency measurement system which can cope with frequency offsets of a much greater frequency range. The

benefits of an increased measurement range include fast scanning of a block of spectrum to locate an COFDM ensemble and hence the relaxation for the requirement for ensembles to be located at fixed predetermined frequencies.

We have discovered that the repeating structure of the CAZAC sequences in the Eureka 147 DAB standard allows a number of digital signal processing operations to be applied to the demodulated data at the receiver to obtain and refine a regular structure whereby the coarse frequency offset may be determined within a much larger range of sub-carrier spacings.

We have also developed a method of verifying that the measure of coarse frequency offset determined by the system does not have a gross misalignment. Gross misalignment can be a problem with certain channel impulse delay spreads which cause severe selective frequency fading.

We have also developed an arrangement which provides a reliability metric or quality measure for the results of the coarse frequency offset measurement and gross misalignment measurement. These metrics are useful during the acquisition phase of a DAB receiver as they provide a quantative measure of the presence of a useful signal and also the dependability of the calculated offset. Furthermore the coarse frequency offset reliability metric can help to distinguish between different modes of a Eureka 147 DAB signal.

Accordingly, in one aspect of this invention there is provided apparatus for measuring the coarse frequency offset

of a multi-carrier or OFDM signal comprising a plurality of sub-carriers at a known relative spacing, the signal including a symbol block including a substantially self-orthogonal sequence which repeats across the sub-carriers, said apparatus including means for processing said multi-carrier signal to obtain a signal having a generally regular data structure, and means for applying a comb filter function generally matched to said structure thereby to determine the coarse frequency offset of said multi-carrier signal.

In the described embodiment, said means for processing includes demodulating means for demodulating the signal to derive data corresponding to each of said sub-carriers. Said means for processing may further include means for correlating the signal with said self-orthogonal sequence or a sequence derived therefrom to resolve the signal to provide a data structure comprising peaks corresponding to regularly spaced sub-carriers. Said processing means may further include means for filtering said data with a shifted version thereof, further to refine the structure of the data. Said processing means may further include means for filtering data with a shifted version thereof to reduce the amplitude of alternate regularly spaced peaks to increase the spacing of the remaining peaks. Said comb filter function is preferably matched to said regularly spaced alternate peaks to provide a data structure in which a maximum peak may be distinguished from the adjacent peaks, from which the coarse frequency offset may be determined.

The apparatus of this invention preferably includes means responsive to the measurement of said coarse frequency offset to adjust the demodulation frequency. The apparatus preferably also includes means for deriving a metric indicative of the reliability of the measurement of said coarse frequency offset. The metric may conveniently be based on the signal to noise ratio of said maximum peak compared to selected relatively low amplitude sub-carriers adjacent said peak. Although the invention is applicable to a wide range of different signals, the multi-carrier signal may be a signal constructed in accordance with European Telecommunications Standard ETS 300401, Modes I, II, III, or IV, and said metric may be used to distinguish between signals of different Modes.

The apparatus may further include alignment checking means responsive to the energy content of said maximum peak and two or more adjacent peaks to determine whether misalignment has occurred and, if so, to provide a correction value. The apparatus may also include means for providing a metric for the misalignment correction.

An example of a suitable calculation is given in the following description.

The invention also extends to a method for measuring the coarse frequency offset of a multi-carrier or OFDM signal which comprises a plurality of sub-carriers at a known relative spacing, the signal including a symbol block including a substantially self-orthogonal sequence which repeats across the sub-carriers, said method including

processing said multi-carrier signal to obtain a signal of a generally regular data structure, applying a comb filter function generally matched to said structure thereby to deduce the coarse frequency offset of said multi-carrier signal.

Whilst the invention has been described above, it extends to any inventive combination or sub-combination of features set out in the above or in the following description.

The invention may be performed in various ways and, by way of example only, a specific embodiment thereof will now be described, reference being made to the accompanying drawings, in which:-

Figure 1 is a schematic diagram of a Eureka 147 DAB transmission frame;

Figure 2 is an example of a CAZAC sequence of length 16.

Figure 3 shows the application of the CAZAC Mode I Eureka 147 DAB rotation sequence of Figure 2 repeated and rotated across the sub-carriers of the sync symbol block;

Figure 4 is a block diagram of the components of a system in accordance with this invention for determining the coarse frequency offset measurement, any gross misalignment, and respective metrics indicative of the reliability of these calculations;

Figure 5 is a plot of the spectrum of a non distorted symbol following frequency re-packaging;

Figure 6 is a plot of the symbol spectrum following

correlation with the CAZAC sequence;

Figure 7 is an enlarged view of part of the plot of Figure 6;

Figure 8 is a plot of the symbol spectrum following subtraction of the shifted left by 64 version;

Figure 9 is an enlarged view of part of the plot of Figure 8;

Figure 10 is a plot of the symbol spectrum following addition of the shifted left by 16 version;

Figure 11 is an enlarged view of part of the plot of Figure 10, and

Figure 12 is a plot of the symbol spectrum following comb correlation

For ease of explanation in the following description, references will be made to the Eureka 147 DAB Mode I, but it will of course be appreciated that the principles described herein are applicable for other modes of this standard as well as for many other OFDM systems.

In Eureka 147 DAB, data is assembled to form a transmission frame as illustrated in Figure 1. The transmission frame is made up of a synchronisation channel comprising a null symbol and a sync symbol. The fast information channel contains typically three symbols which provide information and management data concerning the data contained in the main service channel. The main service channel typically contains 72 symbols. The present invention concerns use of the sync symbol to measure coarse

carrier frequency offsets of up to at least ± 254 kHz (in this particular example). The transmission signal is multiplexed across 1536 sub-carriers spaced at 1kHz and so each symbol may be seen as a block of 1536 carriers.

The data is encoded using a version of quadrature phase shift keying ((QPSK) - more particularly $\pi/4$ D-QPSK)). For a further discussion of the COFDM modulation system, reference is directed to "The COFDM Modulation System: The Heart of Digital Audio Broadcasting", P. Shelswell, *Electron. & Commun. Eng. J., June 1995, pp 127 - 136.*

At the transmitter, a sampled digital signal is defined in the frequency domain, and it is defined such that the discrete Fourier spectrum exists only at discrete frequencies. Each sub-carrier corresponds to one element of this discrete Fourier spectrum. In general, the amplitude and phases of the sub-carriers depend on the data to be transmitted, but in a QPSK system the amplitude is unity and so the phase of each sub-carrier is defined for each transmitted symbol. The transmitter uses an inverse Fast Fourier Transform (FFT) to provide a series of samples which are the time domain representation of the signal. These time samples are then converted to give an analogue signal for transmission.

In the receiver, the reverse process is applied. The signal is converted from its incoming analogue format to a sampled digital representation. The samples corresponding to each symbol are then Fourier transformed into the frequency domain. This gives the amplitude and phase of

each transmitted carrier, the change in phase of each carrier from one carrier to the next communicating the information.

As briefly mentioned above, each frame includes a null symbol which is used at the receiver to provide synchronisation. The sync symbol of each frame is based on the repetitive use of a short length (in this example 16) CAZAC (constant azimuth zero autocorrelation) sequence; see Figure 2 an example of a sequence. This sequence is repeated (and rotated by multiples of $\pi/2$) in a regular manner to occupy all the sub-carriers, as shown in Figure 3. It will be seen that the CAZAC sequence is repeated in pairs and rotated up to the DC value (the central null sub-carrier). It is important to note that after the DC value, the rotation is in the opposite sense $1 \rightarrow -j \rightarrow -1 \rightarrow j \rightarrow 1$..... etc.

Referring to Figure 4 at the receiver, the incoming signal is demodulated to obtain in-phase (I) and quadrature (Q) samples and an FFT is applied to each symbol block. The FFT requires the number of carriers to be a power of 2 (typically 2048) but the actual number of real carriers is less (in this example 1536) and so the other carriers are set to zero.

The processing of the sync symbol to measure the frequency offset will now be described. The aim of the processing is to derive the coarse frequency offset to within ± half a sub-carrier spacing. The embodiment described below returns tracking information including coarse frequency offset, a signal-to-noise measure (which

can be used to distinguish between modes II and III of Eureka 147 DAB) and a lock confidence. The embodiment refers to Mode I but the processing is equally applicable to other Modes. In brief, the sync symbol is correlated with the CAZAC sequence and filtered to give main peaks separated by 32 sub-carriers (32 kHz). These peaks are correlated with a comb filter matched to the known orientation of the peaks with the result that the diversity is increased to ±64 kHz. The comb helps to localize the data because it accounts for the dip in magnitude of the peaks that occur near the ends of the ensemble and near the centre frequency.

A validity check is need to ascertain the reliability of the result and to provide a reliability metric. The signal-to-noise ratio between the chose correlation peak and the low between-peaks correlation is used.

In certain fading environments it can be very difficult to distinguish the correct peak from the competing peaks to either side at ±64 kHz. An energy method is used to provide an alignment measure of the chosen peak and again a reliability metric is obtained for this measure.

Referring again to Figure 4, the I and Q samples (sample rate F_s) are subjected to an FFT to obtain a complex vector $\mathbf{r}=\{r_0 \ldots r_{N-1}\}$ of frequency domain samples. A total of K components of $\mathbf{r}$ correspond to data sub-carriers F_s/N Hz apart. For the Eureka 147 DAB sync symbol these are differentially encoded CAZAC sequences repeated in a manner described in the European Telecommunications Standard ETS 300401. In this embodiment, the method of determining the

coarse frequency offset is based on exploiting the properties of this particular sequence. In the following, the complex CAZAC sequence is denoted by vector $c=\{c_0.....c_{M-1}\}$ (M=16 in Eureka 147 DAB) and (*) denotes complex conjugation.

Step 1: Frequency repackaging

In this step the positive and negative frequency halves of the FFT result are swapped:-

$$r_n \leftrightarrow r_{N/2+n} \qquad n = 0...N/2-1$$

(Equation 1)

As noted earlier, the FFT has 2048 channels whereas there are 1536 actual sub-carriers with the remainder of the frequencies being set to zero. Consequently the FFT produces two blocks at either end of the spectrum with a gap in the middle. This frequency re-packaging step constructs a single block and, whilst not essential, simplifies subsequent indexing. The rearranged data is shown in Figure 5.

Step 2: Differentially Decode

vector **r** is differentially decoded giving vector **u**:

$$u_n = r_{n+1} r_n^{*} \qquad n = 0...N-2$$

(Equation 2)

In Eureka 147 DAB the signal transmitted includes a

differentially encoded version of the CAZAC sequence and this step undoes this to recover the CAZAC sequence.

Step 3: Correlate with CAZAC Sequence

Vector **u** is correlated with the CAZAC sequence (**c**), giving vector **d**.

$$d_n = \sum_{i=0}^{M-1} u_{n+i} c_i^* \qquad n = 0 \ldots N - M - 1$$

(Equation 3)

This step (see the spectrum in Figures 6 and 7) resolves the underlying CAZAC sequence rotations, resulting in main peaks every 16 sub-carriers, with the rotation sequence of

1 1 j j -1 -1 -j -j........ beginning with the lowest numbered sub-carrier. This continues until the centre of the spectrum upon which the rotation order reverses to 1 1 -j -j -1 -1 j j .... It is noted that the presence of a DC sub-carrier in the very centre causes the first peak in the second half to be 17 rather than 16 sub-carriers from the preceding peak. Apart from this the correlation gives a peak every 16th sub-carrier and mostly zeroes elsewhere

Step 4: Filtering (first stage)

A vector **e** is obtained by subtracting a shifted left by 64 version of **d** as follows:-

$$e_n = d_n - d_{n+64} \qquad n = 0 \ldots N - M - 65$$

(Equation 4)

In this step (see the spectrum in Figures 8 and 9) the following sequence is obtained:

2 2 2j 2j -2 -2 -2j -2j........... 2 2 2j 2j -1 -1 -j -j (0) 2 2 -2j -2j -2 -2 2j 2j........

This allows the centre portion of the spectrum to become visible because the peaks immediately to the left of DC are not reinforced due to the presence of a null sub-carrier.

Step 5: Filtering (first stage)

Vector **f** is obtained by adding a shifted left by 16 version of **e** as follows:

$$f_n = e_n + e_{n+16} \qquad n = 0 \ldots N - M - 81$$

(Equation 5)

In this step the following sequence is obtained:

4 2+2j 4j -2+2j -4 -2-2j -4j......... 4 2+2j 4j -1+2J -2 -1-j -2j (0) 4 2-2j -4j -2-2j -4 -2-2j 4j........ This reduces every second peak to be 3dB lower than the main peak, thus widening the discrimination to 32 sub-carriers, as seen in Figures 10 and 11.

Step 6: Correlation with Comb Filter

Vector **f** is correlated with a comb filter **h** using a location vector to form a vector **g**:

$$g_n = \sum_{i=0}^{N_h - 1} f_{n+l_i} h_i^* \qquad n = 0 \ldots N/4 - 2$$

(Equation 6)

By way of illustration the comb filters **h** and location vectors **i** for the various modes in Eureka 147 DAB are given

in Appendix A. In this step the vector is correlated with a comb filter matched to the main peaks:-

1 j -1 -j ...... 1 j $-\frac{1}{2}$ $-\frac{1}{2}j$ (0) 1 -j -1 ......1 -j

This step utilises the fact that the rotation direction of length 32 sub-sequences in the second half of the spectrum is opposite to that of the first half and so the net result is that the peaks at every 32 sub-carriers are zero, thereby increasing the discrimination to 64 sub-carriers. In Mode I currently under direct consideration there is little to be gained from correlating with the $\frac{1}{2}$s especially as they are two bins wide, although it may be worthwhile for Mode II and especially Mode III to correlate against the peaks 3dB down. The resultant symbol spectrum is shown in Figure 12.

Step 7: Locate Maximum Peak

The index of the maximum of g is obtained:

$$k = \arg\max_n |g_n| \qquad n = 0 \ldots N/4 - 2$$

(Equation 7)

Step 8: Coarse Offset

The coarse offset (in units of sub-carrier spacing) is given by

$$\Delta f_c = k - N/8$$

(Equation 8)

In this way, the coarse carrier frequency offset may be measured to approximately ± 256 sub-carriers (e.g. ± 256 kHz in Mode I transmissions).

In order to obtain a coarse frequency offset reliability metric, a ratio may be taken between the energy of the maximum peak, g_k and that of adjacent correlation values. In a first step the correlations at offsets specified in a location vector **p** (see Appendix A) are summed:

$$\sigma^2 = \frac{1}{N_p} \sum_{i=0}^{N_p - 1} g_{k+p_i} g^*_{k+p_i}$$

(Equation 9)

The metric m_{off} is then calculated:-

$$m_{off} = g_k g_k^* / \sigma^2$$

(Equation 10)

Here the signal-to-noise ratio based on the chosen peak and up to 56 adjacent points is determined. More or less points may be included. Steps must be taken to avoid overrunning the end of the vector.

The data is also checked to ensure that a gross misalignment of 64 sub-carriers has not occurred.

In this calculation the sync symbol is denoted by the length N complex vector s, comprising unit amplitude CAZAC sequences.

Step 1

The energy of received signal **r** is determined forming r_e:

$$r_e = \sum_n r_n r_n^* \qquad n = 0 \ldots N-1 \qquad \text{(Equation 11)}$$

Step 2

Repeat steps 3 to 5 with $i=-a_r \ldots\ldots a_r$. For Eureka 147 DAB a_r can be a low number, of the order 1 or 2.

Step 3

Vector **r** is cyclically rotated by 64**i** places giving **r'**.

Step 4

r' is correlated with **s** forming r'_e:

$$r'_e = \sum_n \left| r'_n s_n^* \right|^2 \qquad n = 0 \ldots N-1$$

(Equation 12)

Step 5

The energy difference is recorded

$$a_i = r_e - r'_e$$

(Equation 13)

Step 6

The index of the minimum value of a_i is recorded.

$$k = \arg\min_i a_i$$

(Equation 14)

Step 7

The correction is added to the coarse offset.

$$\Delta f_c = \Delta f_c + 64k$$

(Equation 15)

The misalignment correction operates on the basis of finding the energy of the signal and comparing it with the energy of the frequency shifted signal multiplied by the conjugate of the transmitted signal. The energy of the correct alignment will be closest to the energy of the signal and hence the difference will be the lowest. Following the misalignment calculations a confidence measure or alignment metric results naturally. This is a number between 0 and 1, whereby 1 indicates that there is no misalignment uncertainty, whilst a value of 0 indicates a considerable amount of misalignment uncertainty.

Step 1

The minimum value of a_i is determined, excluding a_k:-

$$a_{\min 2} = \min_{i \neq k} a_i$$

(Equation 16)

The alignment metric m_{align} is found thus:

$$m_{align} = 1 - a_k / a_{\min 2}$$

(Equation 17)

Appendi^ A Comb Filters and Location Vectors

Mode I comb filter **h** and location vector **l**. $N_h = 44$

i	0	1	2	3	4	5	6	7	8	9	10	11
h_i	1	j	-1	-j	1	j	-1	-j	1	j	-1	-j
l_i	0	32	64	96	128	160	192	224	256	288	320	352
i	12	13	14	15	16	17	18	19	20	21	22	23
h_i	1	j	-1	-j	1	j	-1	-j	1	j	1	-j
l_i	384	416	448	480	512	544	576	608	640	672	769	801
i	24	25	26	27	28	29	30	31	32	33	34	35
h_i	-1	j	1	-j	-1	j	1	-j	-1	j	1	-j
l_i	833	865	897	929	961	993	1025	1057	1089	1121	1153	1185
i	36	37	38	39	40	41	42	43				
h_i	-1	j	1	-j	-1	j	1	-j				
l_i	1217	1249	1281	1313	1345	1377	1409	1441				

Mode II comb filter **h** and location vector **l**. $N_h = 8$

i	0	1	2	3	4	5	6	7
h_i	1	j	-1	-j	-1	j	1	-j
l_i	0	32	64	96	193	225	257	289

Mode III comb filter **h** and location vector **l**. $N_h = 2$

i	0	1
h_i	1	-j
l_i	0	97

Mode IV comb filter **h** and location vector **l**. $N_h = 20$

i	0	1	2	3	4	5	6	7	8	9	10	11
h_i	1	j	-1	-j	1	j	-1	-j	1	j	1	-j
l_i	0	32	64	96	128	160	192	224	256	288	385	417
i	12	13	14	15	16	17	18	19				
h_i	-1	j	1	-j	1	j	1	-j				
l_i	449	481	513	545	577	609	641	673				

Reliability check location vector **p**. $N_p = 56$:

i	0	1	2	3	4	5	6	7	8	9	10	11
p_i	-32	-31	-30	-29	-28	-27	-26	-25	-24	-23	-22	-21
i	12	13	14	15	16	17	18	19	20	21	22	23
p_i	-20	-19	-18	-14	-13	-12	-11	-10	-9	-8	-7	-6
i	24	25	26	27	28	29	30	31	32	33	34	35
p_i	-5	-4	-3	-2	2	3	4	5	6	7	8	9
i	36	37	38	39	40	41	42	43	44	45	46	47
p_i	10	11	12	13	14	18	19	20	21	22	23	24
i	48	49	50	51	52	53	54	55				
p_i	25	26	27	28	29	30	31	32				

CLAIMS

1. Apparatus for measuring the coarse frequency offset of a multi-carrier or OFDM signal comprising a plurality of sub-carriers at a known nominal relative spacing, the signal including a symbol block including a substantially self-orthogonal sequence which repeats across the sub-carriers, said apparatus including means for processing said multi-carrier signal to obtain a signal having a generally regular data structure, and means for applying a comb filter function generally matched to said structure thereby to deduce the coarse frequency offset of said multi-carrier signal.

2. Apparatus according to Claim 1, wherein said means for processing includes demodulating means for demodulating the signal to derive data corresponding to each of said sub-carriers.

3. Apparatus according to Claim 1 or Claim 2, wherein said means for processing further includes means for correlating the signal with said self-orthogonal sequence or a sequence derived therefrom to resolve the signal to provide a data structure comprising peaks corresponding to regularly spaced sub-carriers.

4. Apparatus according to Claim 3, wherein said processing means further includes means for filtering said data with a shifted version thereof, further to refine the structure of the data.

5. Apparatus according to Claim 3 or Claim 4, wherein

said processing means further includes means for filtering data with a shifted version thereof to reduce the amplitude of alternate regularly spaced peaks to increase the spacing of the remaining peaks.

6. Apparatus according to Claim 5, wherein said comb filter function is matched to said regularly spaced alternate peaks to provide a data structure in which a maximum peak may be distinguished from the adjacent peaks, from which the coarse frequency offset may be determined.

7. Apparatus according to any of the preceding Claims including means responsive to the measurement of said coarse frequency offset to adjust the demodulation frequency.

8. Apparatus according to any of the preceding Claims, which includes means for deriving a metric indicative of the reliability of the measurement of said coarse frequency offset.

9. Apparatus according to Claim 8 when dependent on Claim 6, wherein said means derives said metric based on the signal to noise ratio of said maximum peak compared to selected relatively low amplitude sub-carriers adjacent said peak.

10. Apparatus according to any of the preceding Claims, wherein said multi-carrier signal is a signal constructed in accordance with one of European Telecommunications Standard ETS 300401, Modes I, II, III or IV, and said metric is used to distinguish between signals of different Modes.

11. Apparatus according to Claim 6, further including

alignment checking means responsive to the energy content of said maximum peak and two or more adjacent peaks to determine whether misalignment has occurred and, if so, to provide a correction value.

12. Apparatus according to Claim 11, including means for providing a metric for the misalignment correction.

13. A method for measuring the coarse frequency offset of a multi-carrier or OFDM signal which comprises a plurality of sub-carriers at a known relative spacing, the signal including a substantially self-orthogonal sequence which repeats across the sub-carriers, said method including processing said multi-carrier signal to obtain a signal of a generally regular data structure, applying a comb filter function generally matched to said structure thereby to deduce the coarse frequency offset of said multi-carrier signal.

14. A method for distinguishing between different modes of a signal constructed substantially in accordance with one of ETS 300401 Modes I, II, III or IV, which comprises measuring the coarse frequency offset of the signal, deriving a metric indicative of the reliability of said measurement, and using said metric to distinguish the Mode of said signal.

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Claims searched:	1 to 14	**Date of search:**	27 April 1998

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4P (PAL)

Int Cl (Ed.6): H04L (27/26)

Other: ONLINE : WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2311445 A	MOTOROLA	None
A	GB 2310118 A	MITSUBISHI	None
A	EP 0529421 A2	DAIMLER-BENZ	None
A	WO 95/07581 A1	THOMSON-BRANT	None

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.